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DESCRIPTION AND CALIBRATION OF THE AEDC LOW SPEED WIND TUNNEL (V/STOL)

T. W. Binion, Jr.

ARO, Inc.

December 1970

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ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The test reported herein was sponsored by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 63725F.

Results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the AEDC, Arnold Air Force Station, Tennessee, under Contract F40600-71-C-0002. The test was conducted on July 11 and 18, 1969 under ARO Project PD3014, and the manuscript was submitted for publication on October 19, 1970.

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This technical report has been reviewed and is approved.

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Facility Development Division
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Director of Civil Engineering

ABSTRACT

The AEDC Low Speed Wind Tunnel (V/STOL) is a continuous-flow, closed-circuit, atmospheric-total-pressure wind tunnel with a 30- by 45-in. test section. This report presents a complete description and the calibration results for the test unit.

CONTENTS

APPENDIX
ILLUSTRATIONS

NOMENCLATURE

p	Pressure, psfa
q	Dynamic pressure, psf
T	Temperature, °F
U	Axial velocity, ft/sec
Y	Distance from the tunnel wall
δ	Boundary-layer thickness

SUBSCRIPTS

s	Nozzle exit conditions
t	Stagnation conditions
∞	Free-stream conditions

SECTION I
INTRODUCTION

The Low Speed Wind Tunnel (V/STOL) was acquired to investigate problems associated with the design and operation of a proposed large low-speed wind tunnel. However, the testing demand has induced a change in classification of the tunnel from a research facility to a test unit. The availability of the tunnel for User tests has created a need for documentation of the tunnel's capabilities.

The calibration program consisted of measuring the centerline static pressure distribution over the operating envelope of the tunnel. Calibration data were obtained with two test-section configurations. The first configuration was a closed test section, all four walls solid, and the second had solid vertical walls and open horizontal walls. Calibration velocities ranged from 20 to 220 ft/sec, although speeds as low as 5 ft/sec can be obtained.

SECTION II
APPARATUS

2.1 WIND TUNNEL

The V/STOL tunnel, shown in Fig. 1 (Appendix I), is a continuous-flow, closed-circuit, atmospheric-total-pressure wind tunnel. The general arrangement of the tunnel is shown in Fig. 2. Flow is generated by a single-stage, fixed-pitch, 67-in.-diam fan. The fan is belt driven by a 100-hp electric motor through a variable-speed magnetic clutch. The fan speed is continuously controllable from 50 to 1060 rpm.

The tunnel nozzle has a contraction ratio of 5.76 ending in a 30- by 45-in. rectangular cross section. The nozzle contour is based on the criteria that

$$\left(\frac{\partial^2 U}{\partial x^2}\right)_{\text{centerline}} \propto \sin\left(\pi \frac{x}{\ell}\right)$$

where x is the centerline distance and ℓ the contraction length.

The test section shown in Fig. 3 has a 30- by 45-in. cross section and is 72 in. long. The horizontal test-section walls are supported by a variable number of support columns which allow a wide flexibility in the selection of ventilated wall configurations. The test-section sidewalls are solid and hinged for access to the model. The first two feet of each diffuser wall is hinged, permitting an angle variation from 1-deg converged to 7-deg diverged. The variable diffuser flap was incorporated to assist in recovering the tunnel flow when operating in the ventilated horizontal-wall mode. The test section is enclosed in a plenum which permits a free-stream static pressure field to be maintained around the test section.

The test section is equipped with a sector-type sting support system. A model may be pitched from -6 to 16 deg about a pitch center located at Station 36.25. The vertical position of the pitch center can be varied from 5 in. above to 9 in. below the test-section centerline. The pitch sector contains a passage for high pressure nitrogen with an area equivalent to a 3/4-in. pipe.

The stilling chamber contains an aluminum honeycomb to reduce turbulence. The honeycomb is 6 in. thick with a 3/8-in. cell size, giving a length-to-diameter ratio of 16. In addition, three 40-mesh screens are installed immediately downstream of the honeycomb.

The tunnel is equipped with an air exchanger, which has exit flaps in the cross leg upstream of the test section and reentry flaps in the diffuser just ahead of the fan. The air exchange ratio may be varied from 0 to 20 percent. The air exchanger's performance and effect on tunnel operation are reported in Ref. 1.

The tunnel also contains a throttle located in the diffuser just ahead of the air exchanger reentry flaps. The throttle has been used to obtain tunnel speeds as low as 5 ft/sec (Ref. 2). Complete description and operating characteristics of the throttle are presented in Ref. 3, where it is shown that the throttle has no adverse effect on the test-section flow.

2.2 INSTRUMENTATION

The centerline static pressure distribution was obtained with a 1-in.-diam static pressure probe. The probe which contains 40 orifices was installed at two axial stations to obtain the pressure distribution from Station -9.4 to 64.1. The pressures were measured on a 50-tube inclined manometer filled with Merian Red® oil - specific gravity 0.820 at 80°F. The manometer was inclined 13.1 deg from the horizontal, providing a multiplication factor of 4.41 on the pressure measurement.

All pressure measurements are referenced to the nozzle exit pressure obtained from a static pressure ring at the entrance to the test section (Station -0.25). The absolute value of the static ring pressure is measured with a precision mercury manometer. The tunnel total pressure is obtained from pitot probes located in the stilling chamber.

The tunnel is equipped with permanent wiring to accommodate ten strain-gage balance channels, ten precision pressure transducers, eight thermocouples, and twenty-four conductors for miscellaneous instrumentation. Up to twenty channels may be recorded with an automatic data acquisition system.

2.3 PRECISION OF MEASUREMENTS

The data contained in the report were determined from single-sample measurements. The uncertainties for the data are estimated from instrument precision and calibration curve-fit deviations. All uncertainties are based on a 95-percent confidence level.

The precision of the measurement reported herein is as follows:

p/p_s	U_∞	q_s	p_s
±0.0001	±0.7 ft/sec	±0.15 psf	±0.25 percent

2.4 PROCEDURE

The test-section velocity is set by varying the excitation voltage to the magnetic clutch with a 10-turn precision potentiometer coupled to an appropriate control circuit. The difference between tunnel total pressure and the static ring pressure at the test-section entrance is used to indicate tunnel velocity as described in Section III.

Manometer board data were recorded photographically and processed with semiautomatic film reading equipment and a digital computer. Tunnel temperatures and pressures were hand recorded.

SECTION III
RESULTS AND DISCUSSION

The centerline pressure distributions obtained with a closed test section are presented in Fig. 4 for the velocity range from 20 to 224 ft/sec. The deviation of the centerline pressure from the average value is within the data uncertainty interval over the entire length of the test section between 20 and 60 ft/sec. Since the pressure is so uniform within that range, it is reasonable to assume a similar quality flow as the speed is reduced. Speeds as low as 5 ft/sec may be obtained by using the throttle. It should be noted, however, that, as the test-section flow approaches 5 to 10 ft/sec, the flow can be affected by wind gusts because of normal leakage at construction joints. Thus, care should be exercised when testing at low velocities when external wind speeds are in the neighborhood of the test-section velocity. No difficulty has been encountered, however, at 15 ft/sec even when external winds were twice the test-section velocity.

As the velocity is increased, the length of zero pressure gradient region diminishes. At velocities above 160 ft/sec, a model should ideally be placed between Stations 25 and 60. However, should it be convenient to test in the region between Stations 15 and 25, a buoyancy correction with $dp/d\ell$ = -0.00027 p_∞, psf/ft, should be applied to the data on that portion of the model within the affected region.

The centerline pressure distribution with the horizontal walls open is presented in Fig. 5. In the absence of the horizontal walls the flow reaches equilibrium more quickly than in the solid test-section case. Thus, the test region with zero pressure gradient begins at Station 5. However, because of viscous mixing at the jet boundary, the aft limit of the test region moves forward with increasing velocity to Station 46 at a test-section velocity of 180 ft/sec. A nominal velocity of 180 ft/sec is the maximum attainable with the horizontal walls open because of the inherent increase in losses associated with open-jet test sections.

The average centerline pressure in the test region is shown in Fig. 6. The deviation of the average centerline pressure from the static ring pressure with solid walls is within the uncertainty level of the set pressure. Therefore, the test-section dynamic pressure may be obtained directly from the difference between p_t and p_s. However, in the case of open horizontal walls, a significant correction is necessary. The following empirical relation may be used to compute q for open horizontal walls:

$$q_\infty = p_t - (3.2573\ q_s + 1.0)\ p_s \quad 0 < q_s < 5$$

$$q_\infty = p_t - (1.9342 \times 10^{-5}\ q_s + 1.00006772)\ p_s \quad 5 < q_s < 36$$

where all units are pounds per square foot. The test-section velocity is then obtained from the relation:

$$U_\infty = 58.2 \left[\frac{q_\infty(T_t + 460)}{p_t - q_\infty}\right]^{1/2}$$

The test-section boundary layer was measured at one location (Station 30) on the bottom wall. The boundary-layer profile shown in Fig. 7 is typical of turbulent flow and represented fairly well by a 1/8th power law equation. The boundary-layer thickness, 1.25 in., is essentially independent of velocity in the range of measurements.

SECTION IV
CONCLUSIONS

Calibration of the AEDC Low Speed Wind Tunnel (V/STOL) has resulted in the following conclusions.

1. With a closed test section, a region suitable for aerodynamic testing in the velocity range from 5 to 220 ft/sec lies between Stations 15 and 60. The dynamic pressure in the region may be taken equal to the average dynamic pressure at the nozzle exit.

2. With open horizontal walls a test region of zero pressure gradient lies between Stations 5 and 46 for velocities up to 180 ft/sec. However, the pressure in the test region is not equal to the average nozzle exit pressure. The relation between the nozzle exit conditions and test region may be computed from an empirical equation.

REFERENCES

1. Anderson, C. F. "Wind Tunnel Investigation of the Air Exchanger for the Proposed AEDC V/STOL Wind Tunnel." AEDC-TR-68-20 (AD826486), February 1968.

2. Binion, T. W. "Investigation of the Recirculation Region of a Flow Field Caused by a Jet in Ground Effect with Cross Flow." AEDC-TR-70-192 (AD711665), September 1970.

3. Anderson, C. F. "Wind Tunnel Investigation of the Throttle for the Proposed AEDC Multipurpose Low Speed Wind Tunnel." AEDC-TR-68-189 (AD675550), October 1968.

APPENDIX
ILLUSTRATIONS

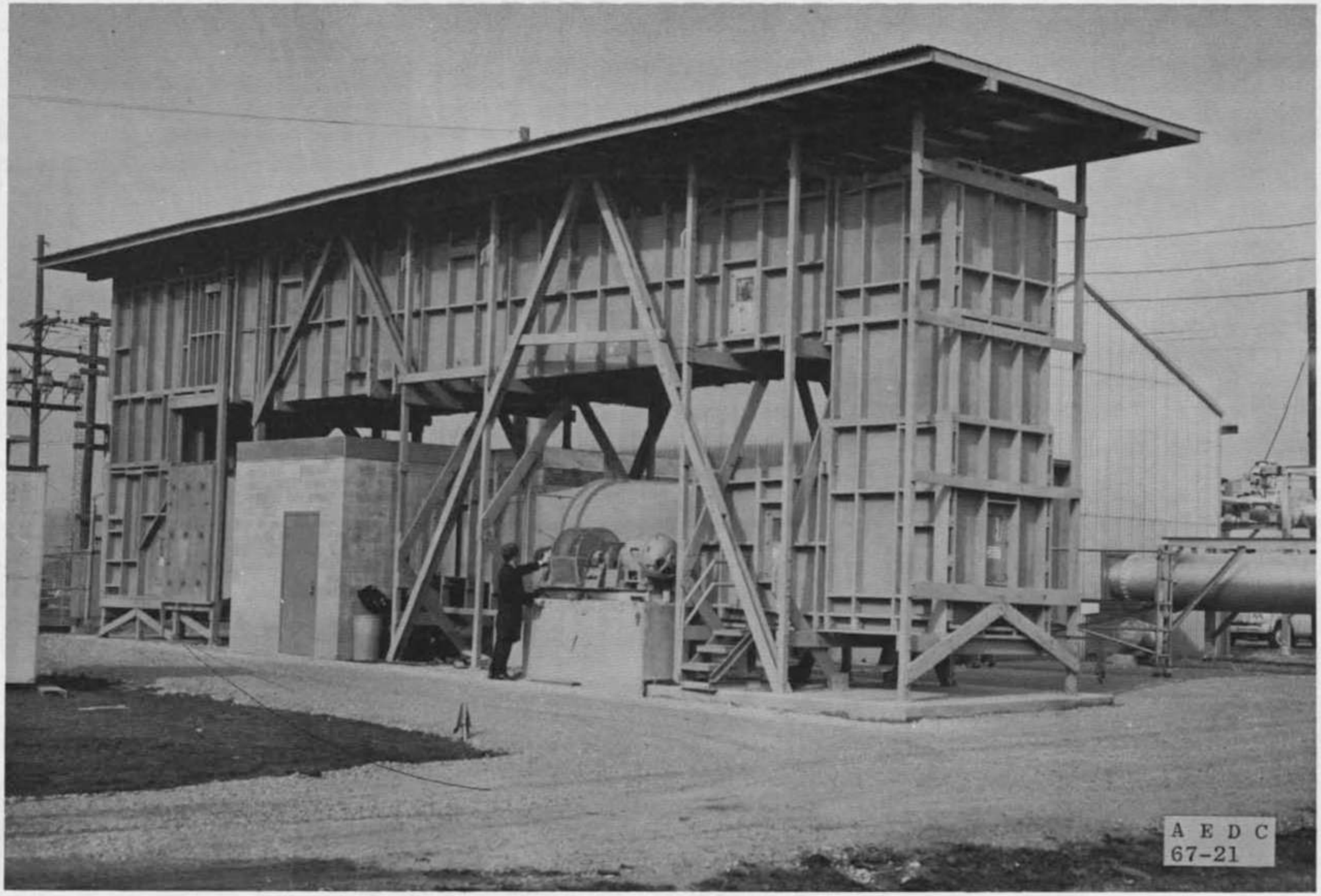


Fig. 1 AEDC Low Speed Wind Tunnel (V/STOL)

NOTE: TEST SECTION 30" x 45" WIDE x 72" LONG
STILLING CHAMBER 6'9" HIGH x 8' WIDE

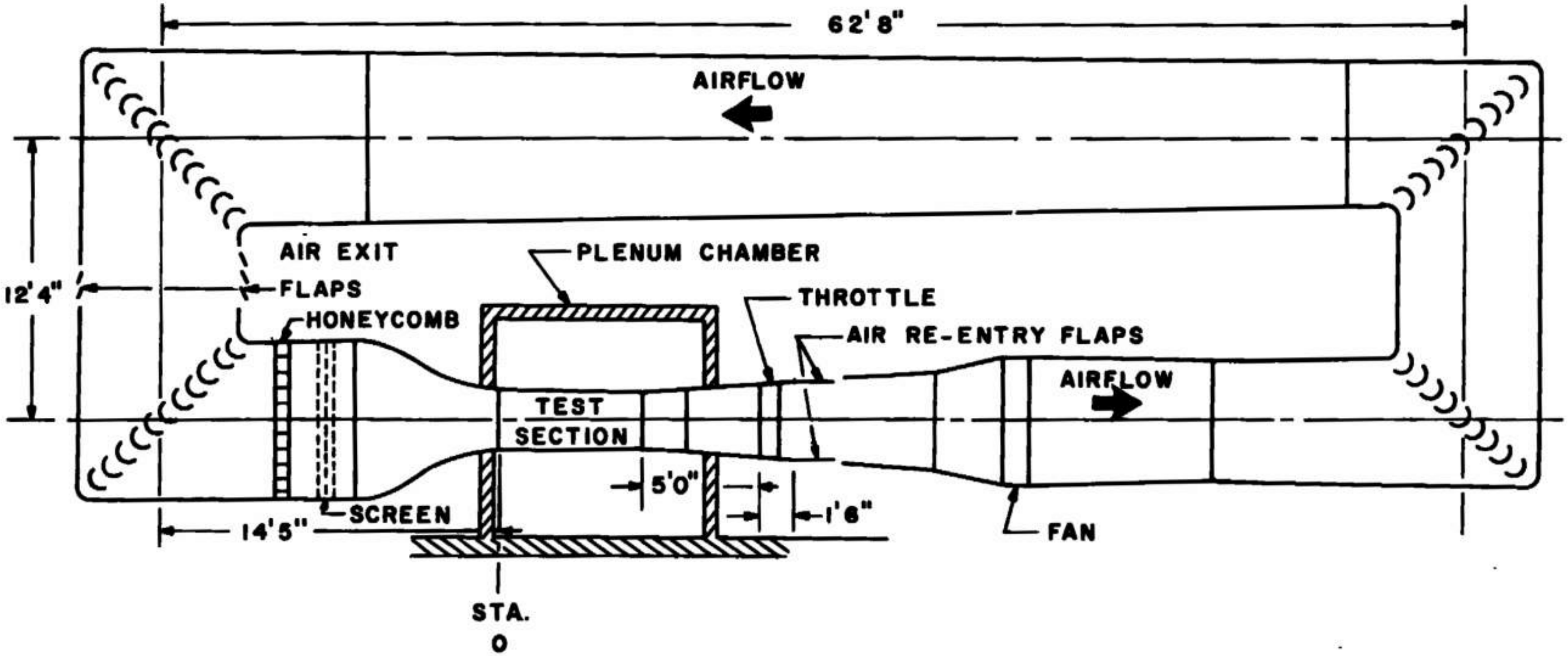


Fig. 2 General Arrangement of the Tunnel

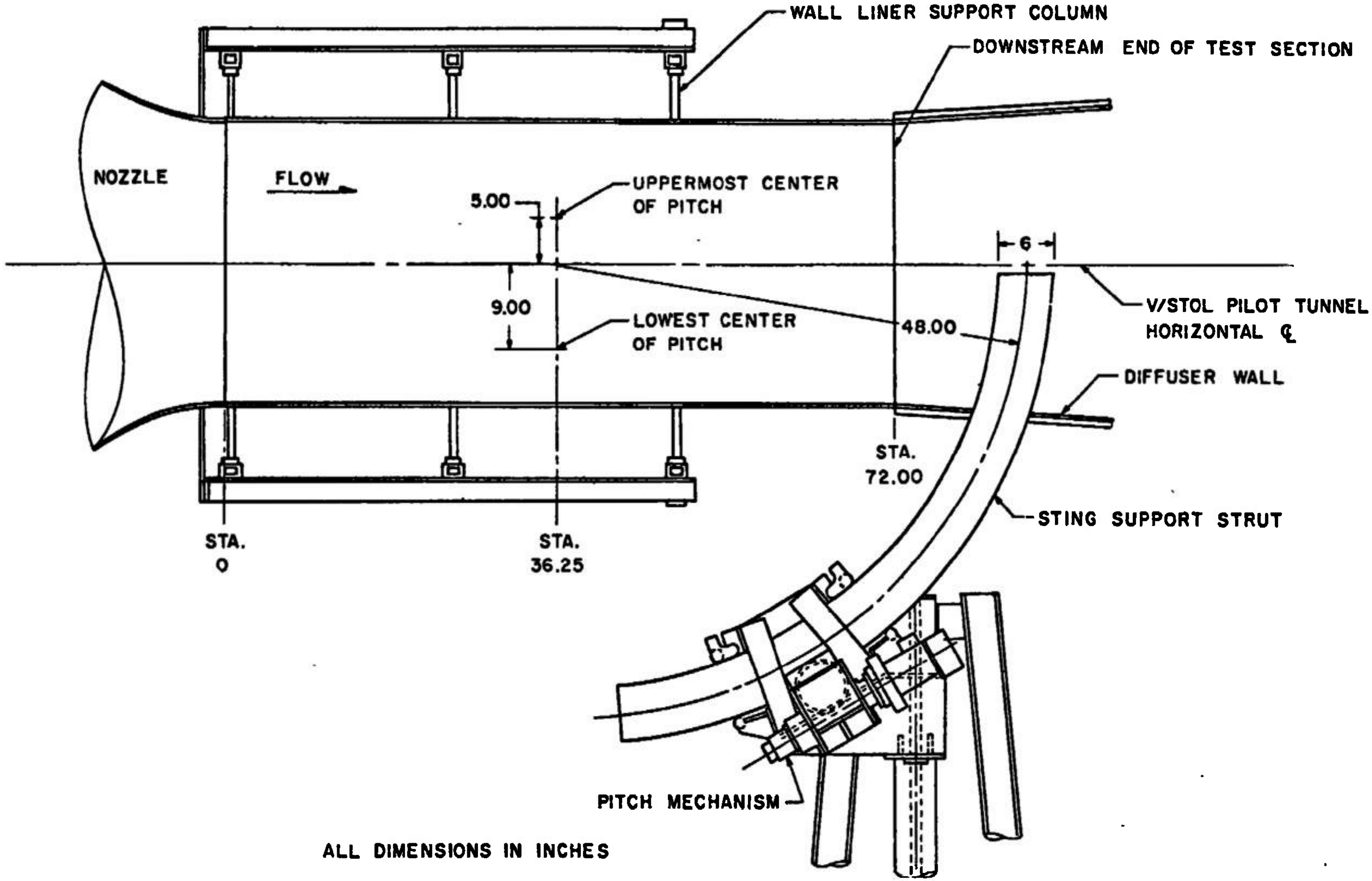
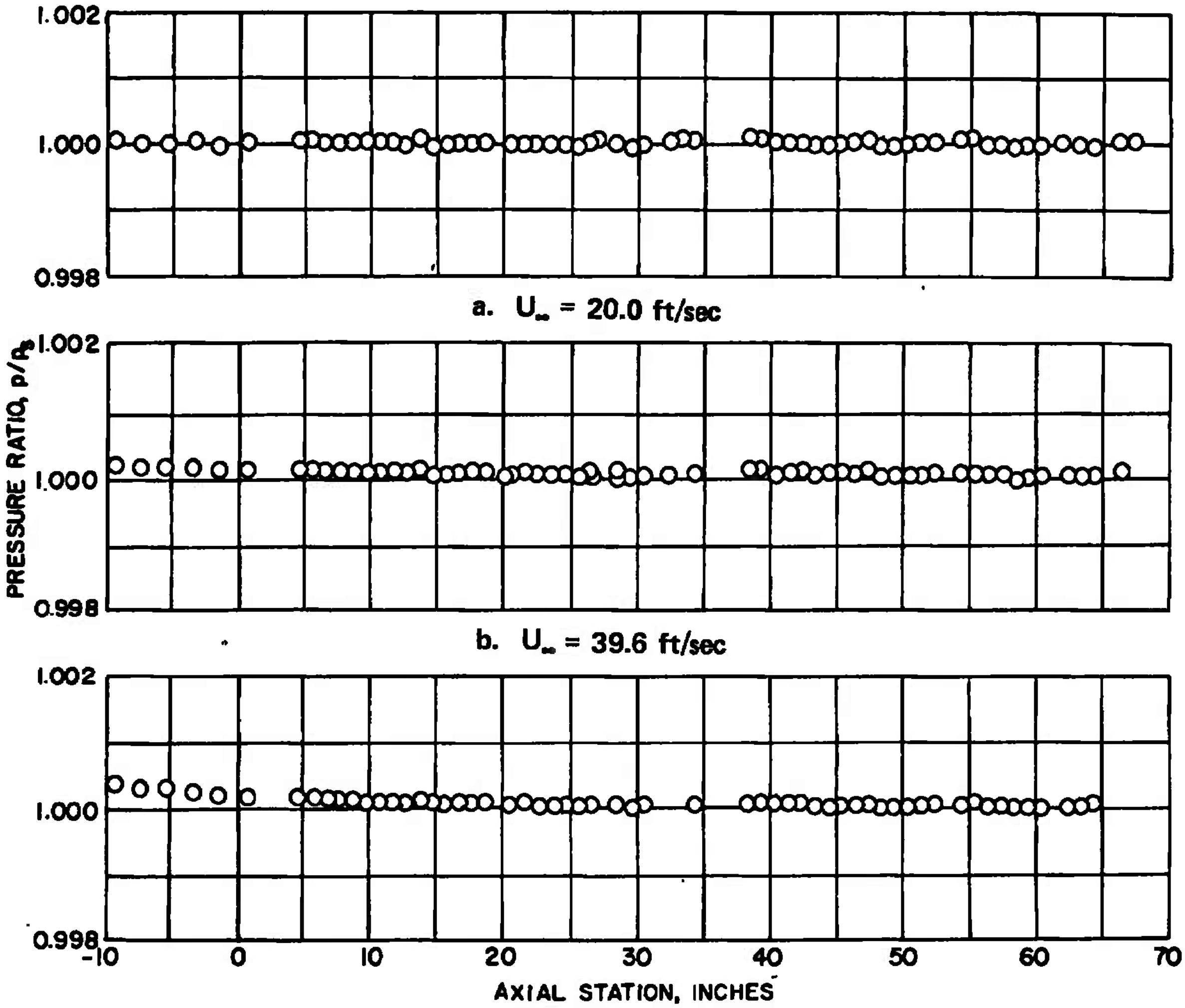
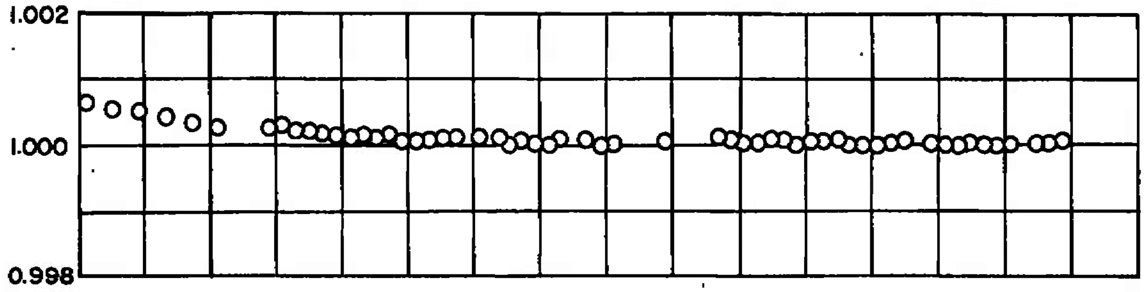


Fig. 3 General Arrangement of the Test Section

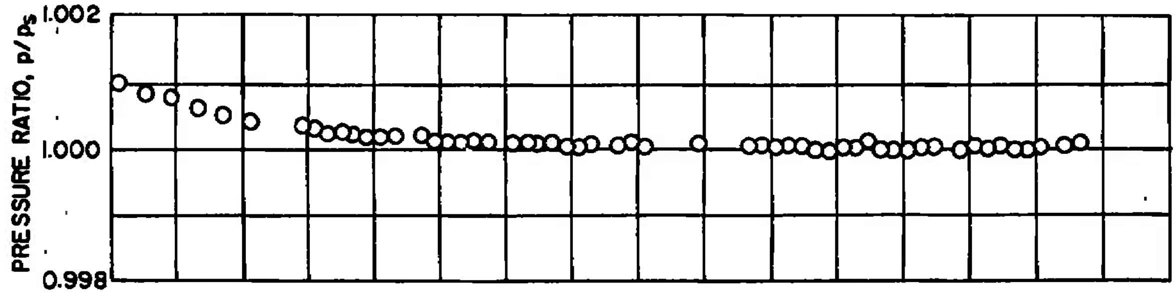


c. U_∞ = 60.5 ft/sec

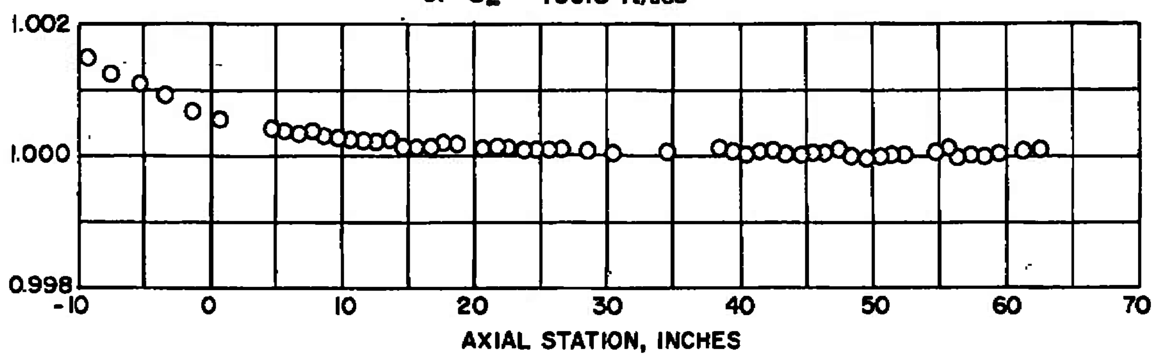
Fig. 4 Centerline Pressure Distribution, Closed Test Section



d. U_∞ = 80.1 ft/sec

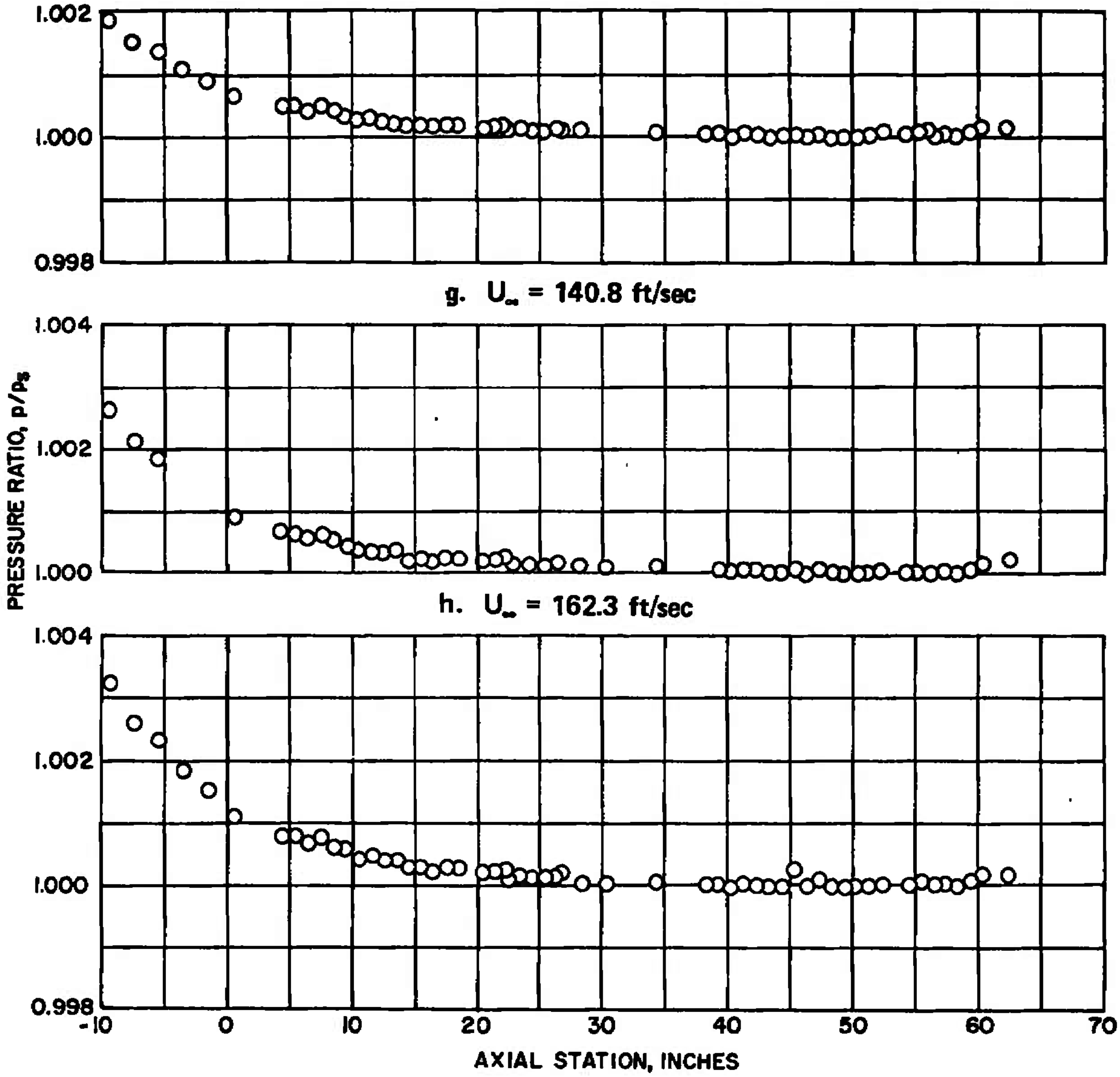


e. U_∞ = 100.5 ft/sec



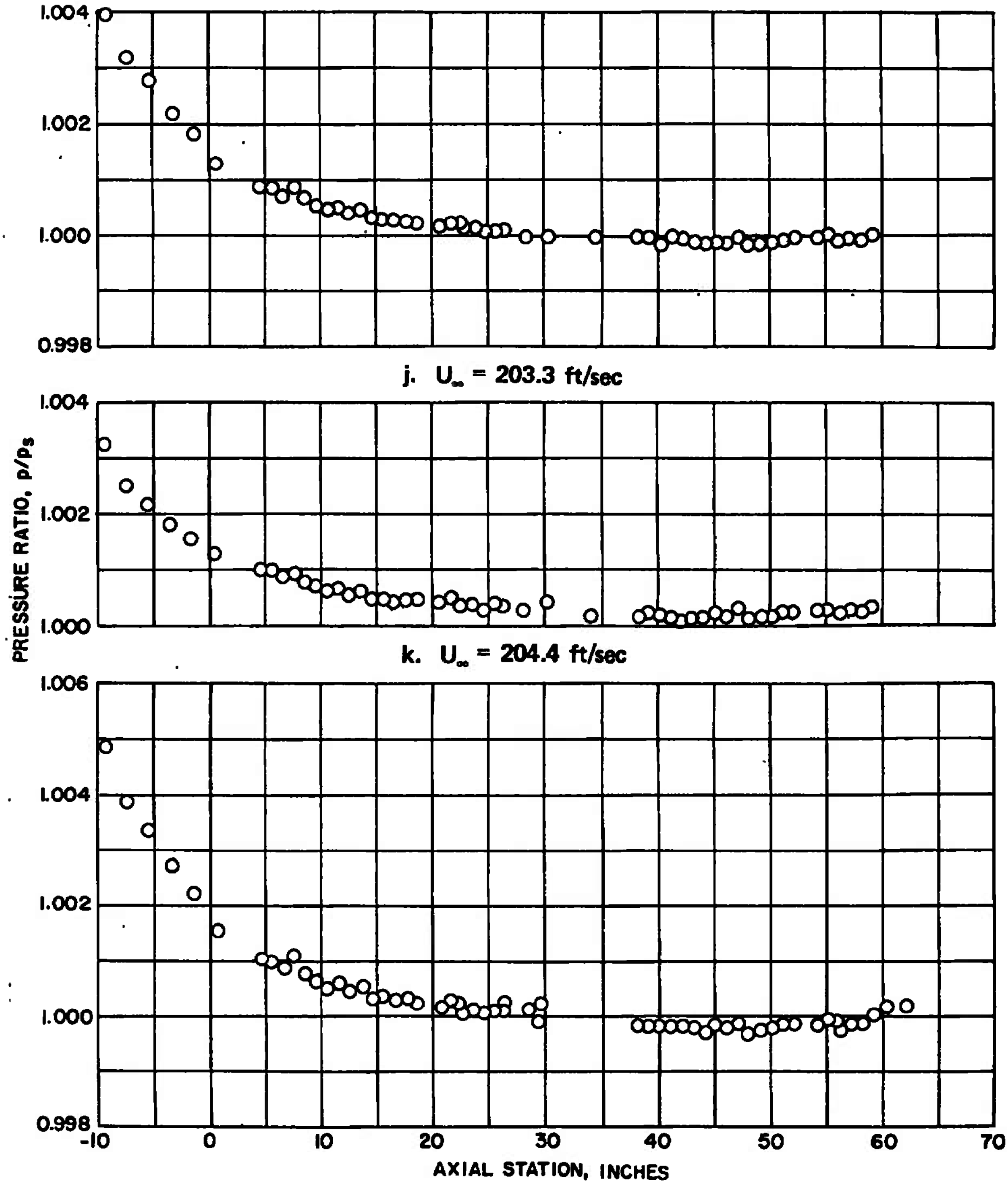
f. U_∞ = 121.4 ft/sec

Fig. 4 Continued

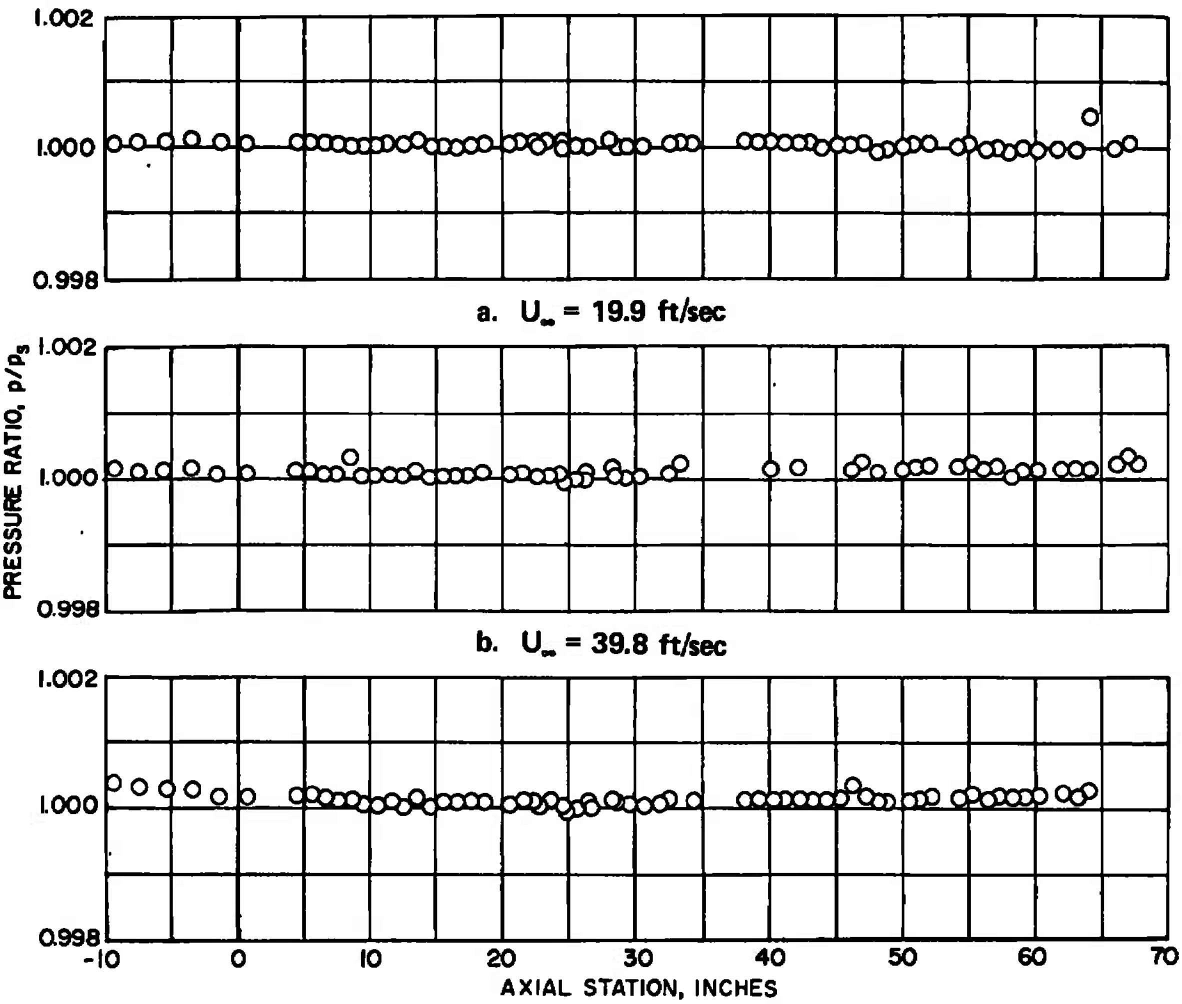


i. U_∞ = 182.2 ft/sec

Fig. 4 Continued

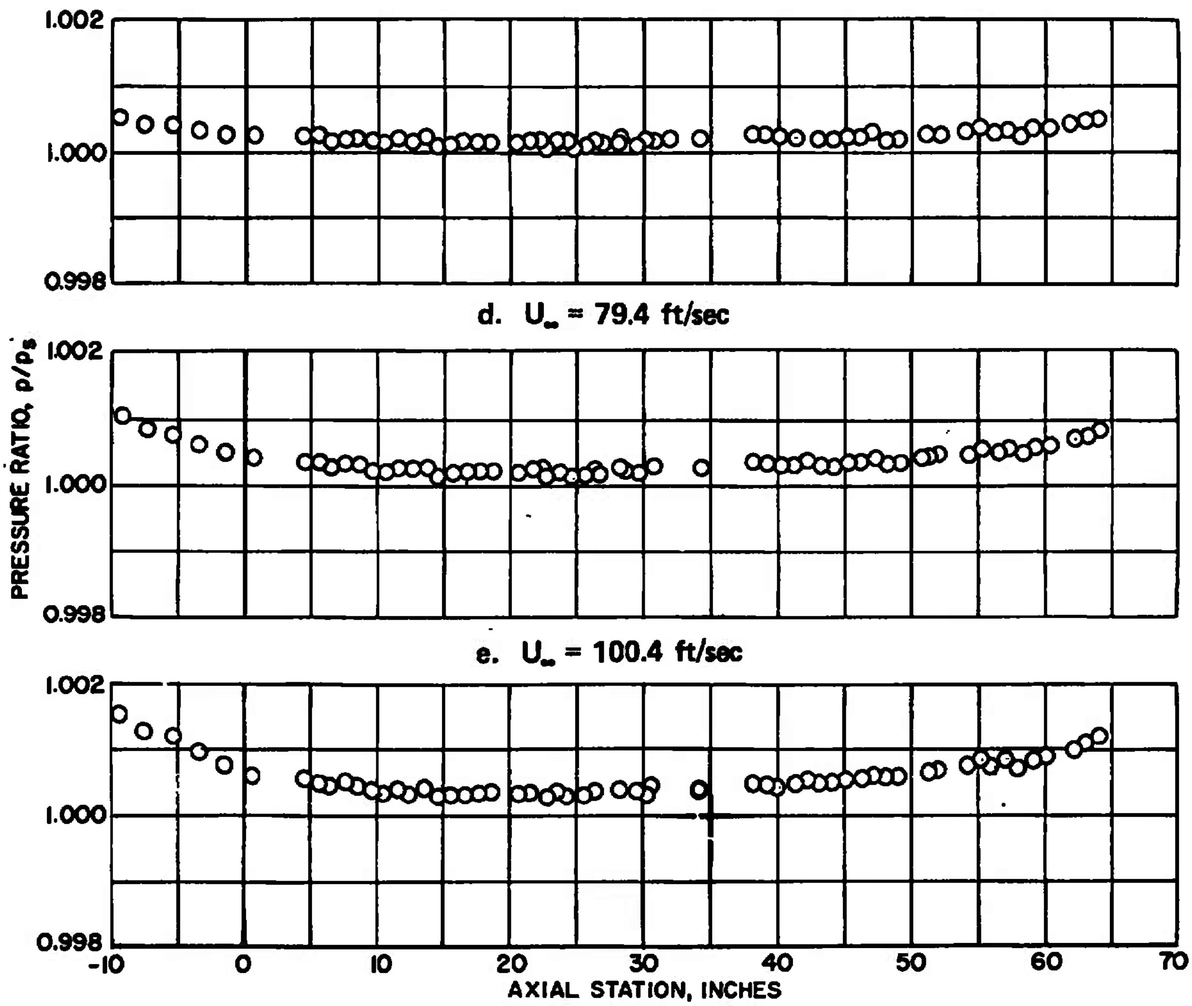


l. U_∞ = 224.3 ft/sec
Fig. 4 Concluded

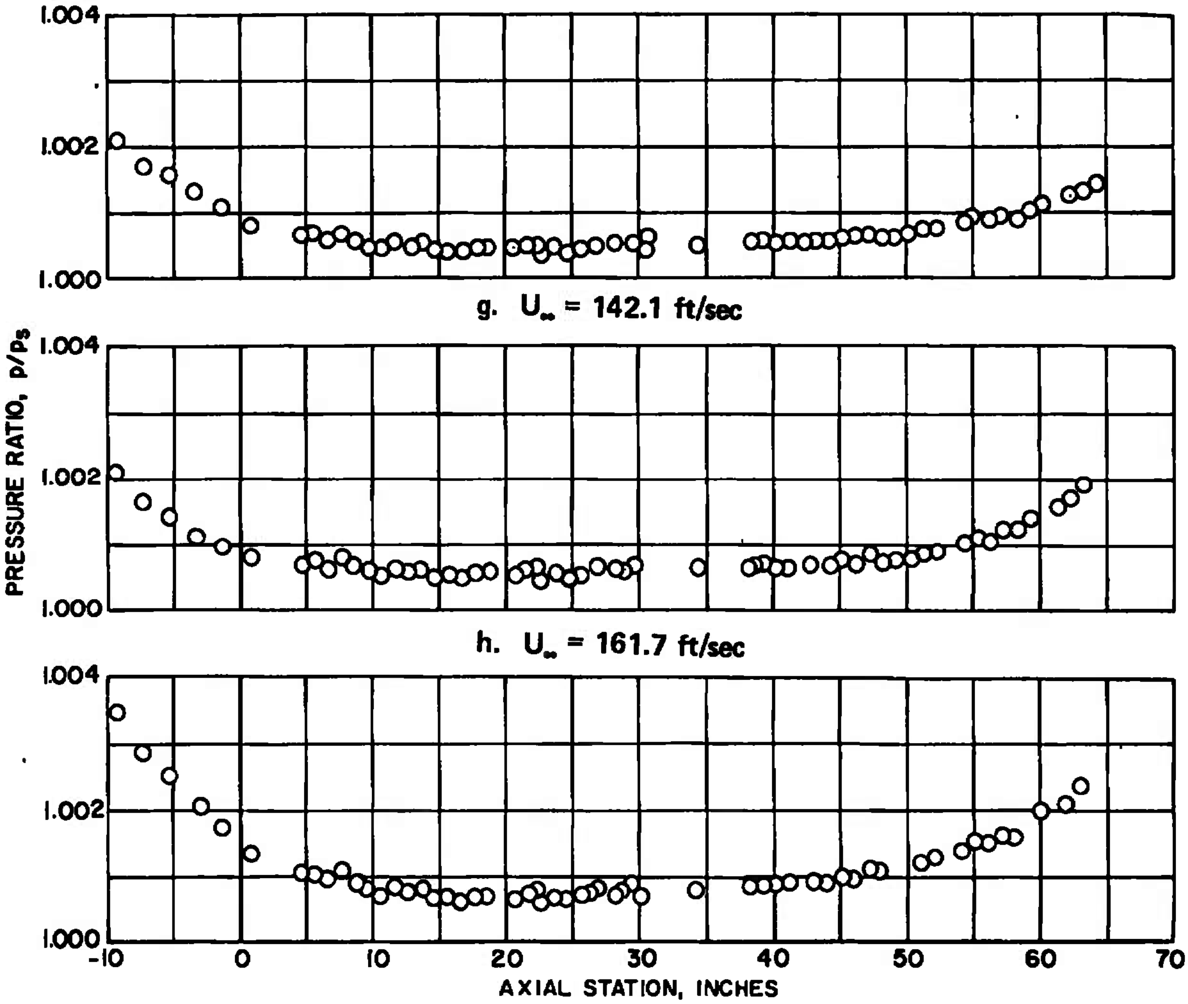


c. U_∞ = 59.7 ft/sec

Fig. 5 Centerline Pressure Distribution, Open Horizontal Walls



f. U_∞ = 121.5 ft/sec
Fig. 5 Continued



i. U_∞ = 183.2 ft/sec
Fig. 5 Concluded

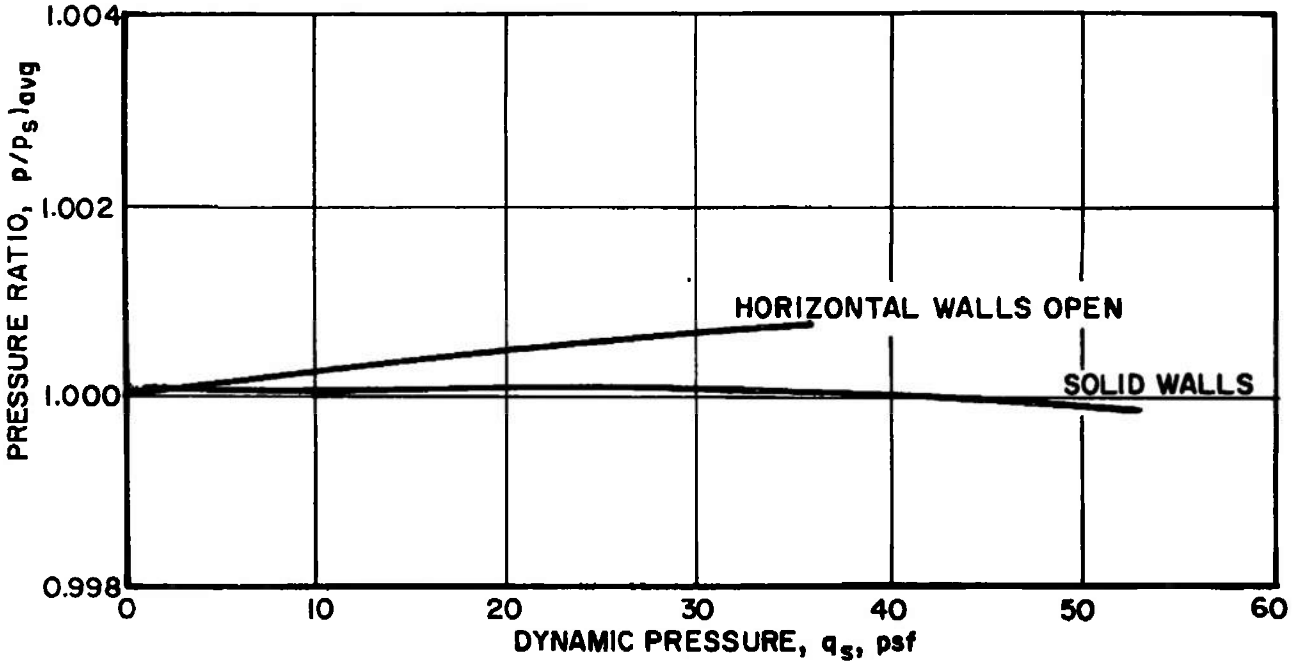


Fig. 6 Average Centerline Pressure within the Test Region

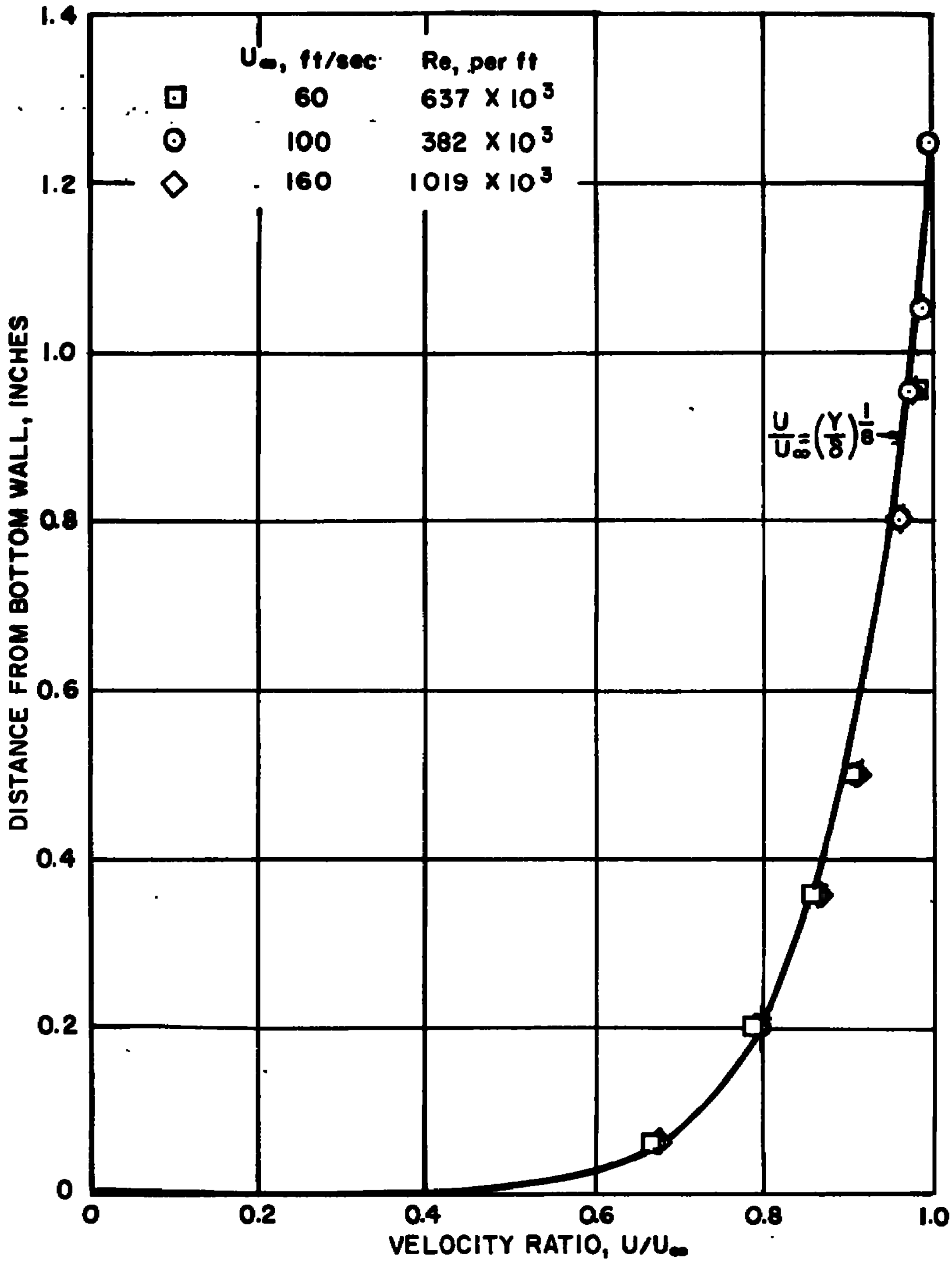


Fig. 7 Boundary-Layer Profile, Station 30, Bottom Wall

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3 calibration " " -- Calibration						
4 V/STOL wind tunnels						
pressure distribution -- Pcwt						

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